A STRUCTURAL ANALYSIS OF AN OCEAN GOING
PATROL BOAT SUBJECTED TO PLANING LOADS

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SUMMARY

A static structural analysis of an ocean going patrol vessel subjected to hydrodynamic planing loads is discussed. The analysis required development of a detailed model that included all hull plating, five structural bulkheads, longitudinal and transverse stiffners, and a coarse representation of the superstructure. The finite element model was developed from fabrication drawings using the Navy CAD system.

The wetted hull surface is subjected to a pressure distribution developed in accordance with the Heller-Jasper planing load formulation. The Heller-Jasper formulation is a recognized standard for planing hull design. This equivalent quasi-static load represents the product of the dynamic planing load and a corresponding dynamic load factor. This pressure distribution varies with percent of hull length from the bow and transverse offset. Some machinery loads, tankage loads, and the weight of the superstructure are included. Symmetry conditions and buoyancy springs have been employed to address the longitudinal symmetry of the ship and the hull displacements respectively.

Various stress and displacement contours are shown for the entire hull. Because several critical areas appeared to be overstressed these areas were remeshed for detail and are presented for completeness.

INTRODUCTION

The U.S. Coast Guard Research & Development Center tasked NUSC Code 44 to perform a static structural analysis of the 110 ft WPB class hull. This hull may experience large hydrodynamic planing loads in heavy seas. This analysis is intended to provide supporting documentation and analysis to verify the structural integrity or to provide information to support possible design modifications to this hull design.

The finite element analysis was divided into two phases. Phase I utilized a coarse mesh model of the entire hull, major bulkheads, and main deck. Phase II consisted of selecting two highly stressed areas from Phase I and remeshing to develop a more detailed stress field in these areas.

In each case, planing loads were applied over the entire wetted hull area in accordance with the Heller Jasper formulation detailed in reference (1). The analysis incorporated some of the significant machinery loads, as well as a coarse estimate of the total superstructure loading on the deck and bulkhead areas.

The analysis was completed using Nastran and was executed on a VAX 11/785 at NUSC. Run times were typically on the order of eight hours.

The results of the analysis consisted of stress contours and displacement contours over the entire modeled areas. Since hull plating is the primary structural area of interest in this analysis - stresses and displacements in the deck and bulkheads are not addressed here.

MODEL DEVELOPMENT

The finite element model of the 110' WPB hull was created from offsets provided by the U.S. Coast Guard. These offsets detailed the hull form via bulkhead locations, longitudinal and transverse stiffeners, and the main deck. These offsets were utilized by the NUSC CAD/CAM system in developing the finite element model used in this analysis.

The steps in this process are shown graphically in figures 1, 2, and 3. Figure 1 represents the offset data provided as a starting point. Figure 2 represents the results of the B spline curve fitting process used to link points into lines. Figure 3 depicts the results of a B spline surface routine which links lines into surfaces representing the hull. Figure 4 represents the final configuration of the hull and superstructure before discretization.

Figures 5 and 6 depict the totally discretized finite element model of the hull, bulkheads, and main deck. This model includes all transverse and longitudinal stiffeners detailed in the original table of offsets. Because the structure is symmetric about the longitudinal plane only one half of the structure requires modelling.

The finite element model utilizes bending plate elements (CQUAD & CTRIA elements) for the hull plate and beam elements (CBARS) in all stiffeners. The bulkheads are corrugated plate structures. An equivalent stiffness smearing approach has been utilized to enable modelling of the bulkheads as a plate structure, this is consistent with the assumptions regarding hull plating as the focus of the analysis.

Upon assembly, the model consists of 2625 quadrilateral plate elements, 590 triangular plate elements, and 2813 beam elements defined by 3094 nodes. Plate thickness were provided by USCG R&D Center and range from 4 pound plate up to 20 pound plate. Longitudinal and transverse member geometries were obtained from blueprints provided by USCG R&D Center and are available from the author.

The results of the analysis of the coarse mesh model indicated that the areas between bulkheads 13 and 17 in the vicinity of the keel warranted closer examination. These areas have been remeshed and are shown in figure 6A.

LOAD GENERATION

Machinery and superstructure loads were specified by the sponsor. Since these loads were not originally part of the load specification, the actual foundations were not modelled, in the interest of completeness these loads were smeared along the appropriate longitudinal and transverse frames. When appropriate, tankage loads were specified.

The primary loading of the hull consisted of a pressure distribution developed in accordance with the Heller Jasper formulation developed in reference (1). This equivalent static load represents the product of the dynamic load and corresponding dynamic load factor. The formulation consists of a pressure distribution that varies with both percent of hull length from the bow and transverse offset. This formulation utilizes an analytical expression for the transverse pressure distribution of the form

$$P = \left[\frac{Po}{2} \; 1 + \cos 2 \; (\frac{z}{G} - \frac{\beta}{2}) \right]$$

where

P is the pressure to be applied at each structural node

Po varies longitudinally in accordance with the hull impact factor specified in figure 7, given two initial values of
Po = 25 PSI and Po = 15 PSI

z, G, and β are based on hull geometry and in accordance with figure 8

A Fortran program utilizing this formulation and generating the appropriate Nastran loading cards (PLOAD2) is available from the author. The gravity loads resulting from all the hull structure has been incorporated in the model as well. Figure 8A shows an overall schematic representation of the loads utilized in this analysis.

BOUNDARY CONDITIONS

The boundary conditions utilized in the problem invoke symmetry along the longitudinal plane by only allowing in plane displacements and rotations. Other than buoyancy, no other boundary conditions required specification.

The buoyancy at each wetted node is accounted for by means of scalar spring elements (CELAS2). These elements are attached to each wetted node and are given a spring constant derived from the ships weight/displacement characteristics. These springs were configured to react in the z direction.

DISCUSSION AND RESULTS

The stress and displacement data has been post-processed using PATRAN in an effort to simplify the graphic representation of a moderate quantity of output data. The data presented here is for the coarse mesh analysis at two values of Po. (25 PSI and 15 PSI) In that this analysis is linear elastic, the 15 PSI values are correctly obtained by scaling the 25 PSI results.

In an effort to facilitate design questions, the stress output is presented in a Von Mises format. Practical considerations encourage utilizing this yield criteria since comparison to tensile stress versus strain performance of the materials used can then be made directly. This failure criteria presumes that yield is the dominant failure mode.

Figure 9 depicts the Von Mises stress contours throughout the hull plating. The highest stress areas are near frames 13 and 17, therein the justification for the fine mesh model. Von Mises stresses in the 25,000 PSI to 45,000 PSI range are clearly visible.

Figure 10 represents minimum principal stresses and figure 11 the maximum principal stresses. These values are used in developing the Von Mises stress contours and are included for completeness.

Figures 12 and 13 depict the displacements in the Y and Z directions respectively. These displacements are shown for Po values of 25 PSI and 15 PSI.

Collectively, the stress data and displacement data justify the remeshing of the area along the keel between frames 13 and 17. As mentioned previously, this area has been remeshed as shown in figure 6A. This finer mesh analysis will result in a more detailed definition of the stress field. It should be noted, however, that overall trends will not change significantly as a result of the finer mesh analysis. Results from this last phase of the analysis will be shown in figures 14, 15, and 16.

CONCLUSIONS

The analysis reported herein indicates that for a material with a Young's Modulus of 30,000,000 PSI and a Poisson's ratio $v = .33$, the maximum Von Mises stresses are 45,000 PSI.

This analysis has not addressed possible fatigue failure modes or corrosion related issues. While fatigue and corrosion are very important NUSC was not tasked to examine these issues.

REFERENCES

1. "On the Structural Design of Planing Craft," by S. R. Heller, N. H. Jasper, Quarterly Transaction RINA, July 1960.

LOOKING AFT

ELEVATION
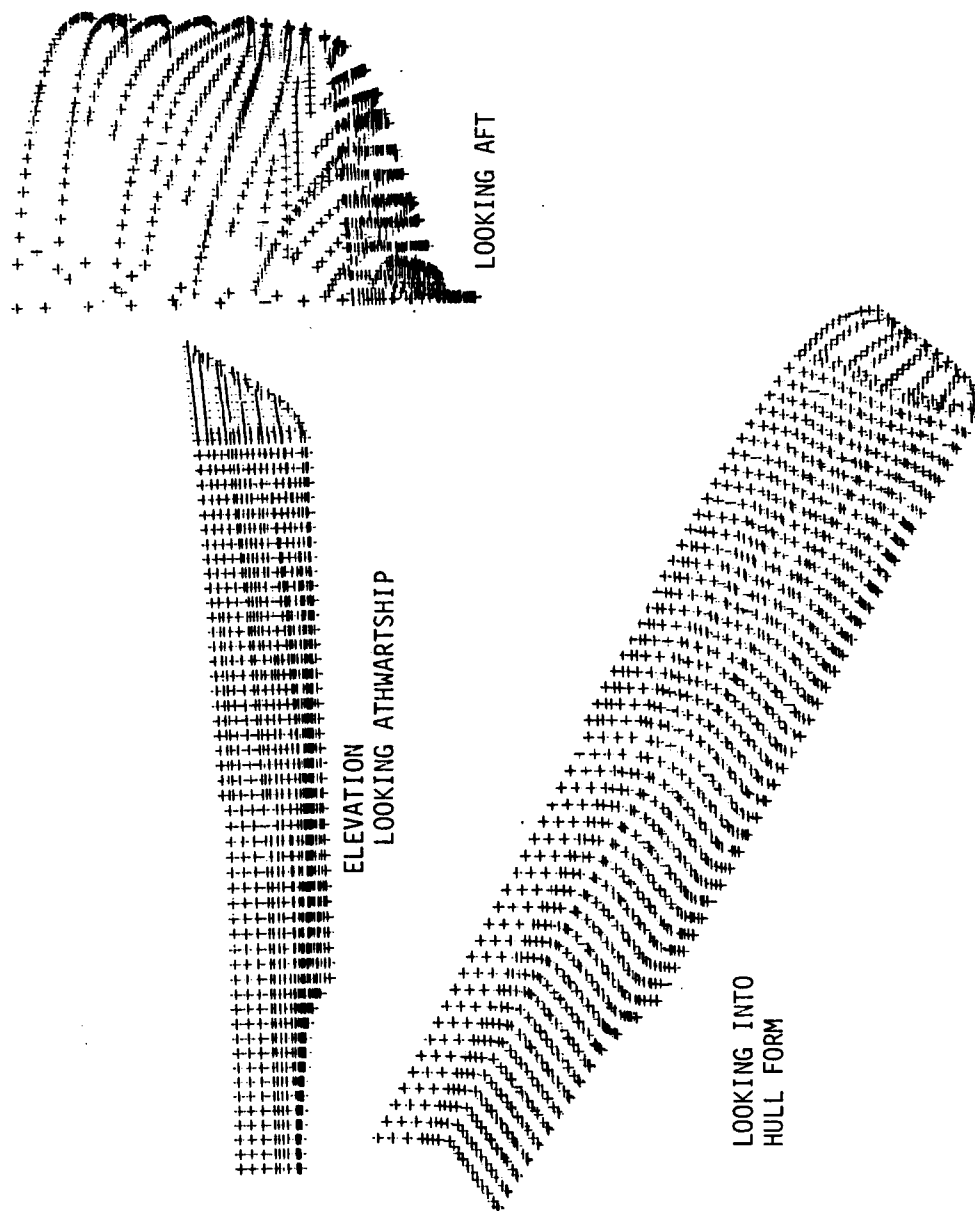LOOKING ATHWARTSHIP

LOOKING INTO
HULL FORM

Figure 1

Spatial Representation of Offsets Used to Define 110 ft WPB Hull and Associated Stiffeners
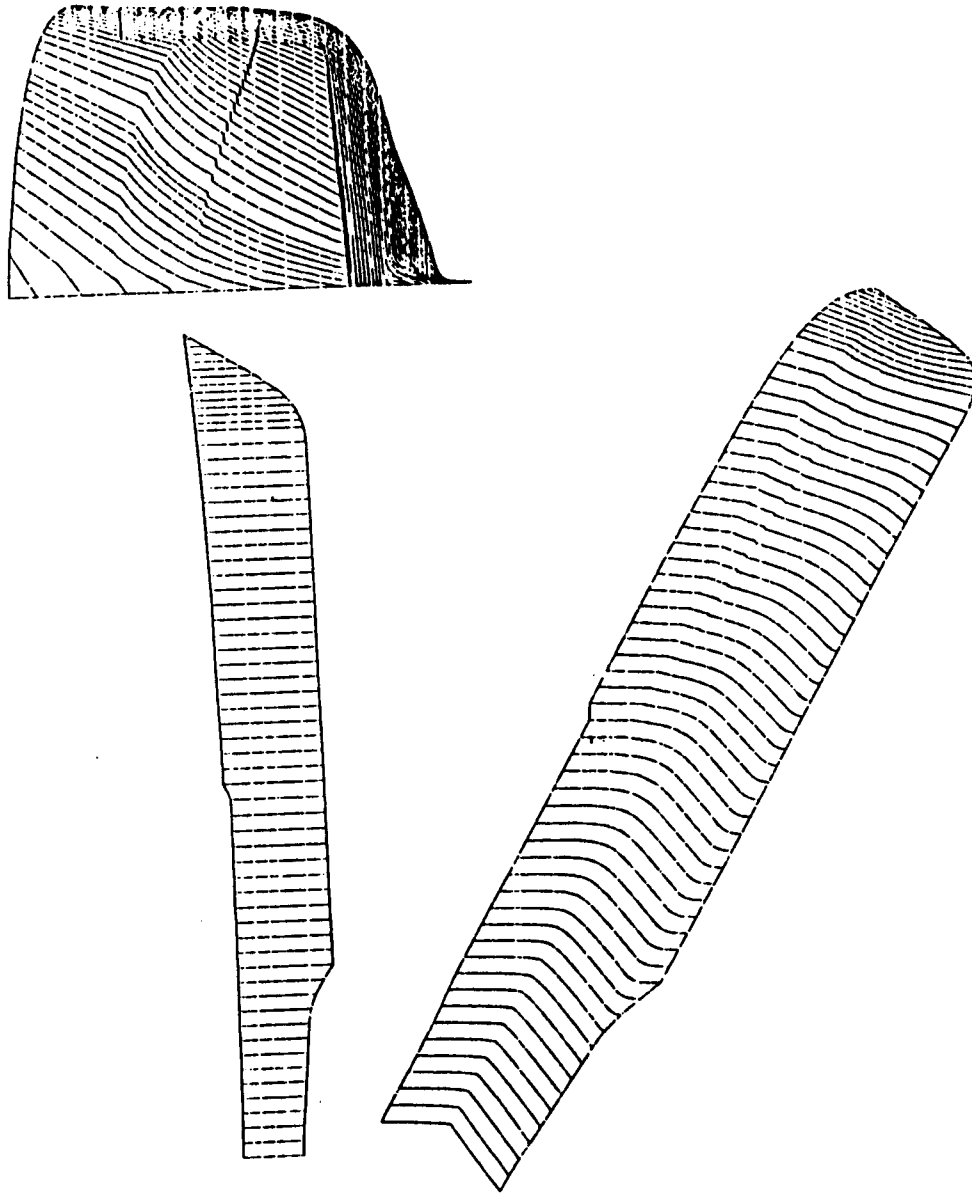
Figure 2

(B-Spline) Fit of Offsets Forming Lines Defining Hull Sections
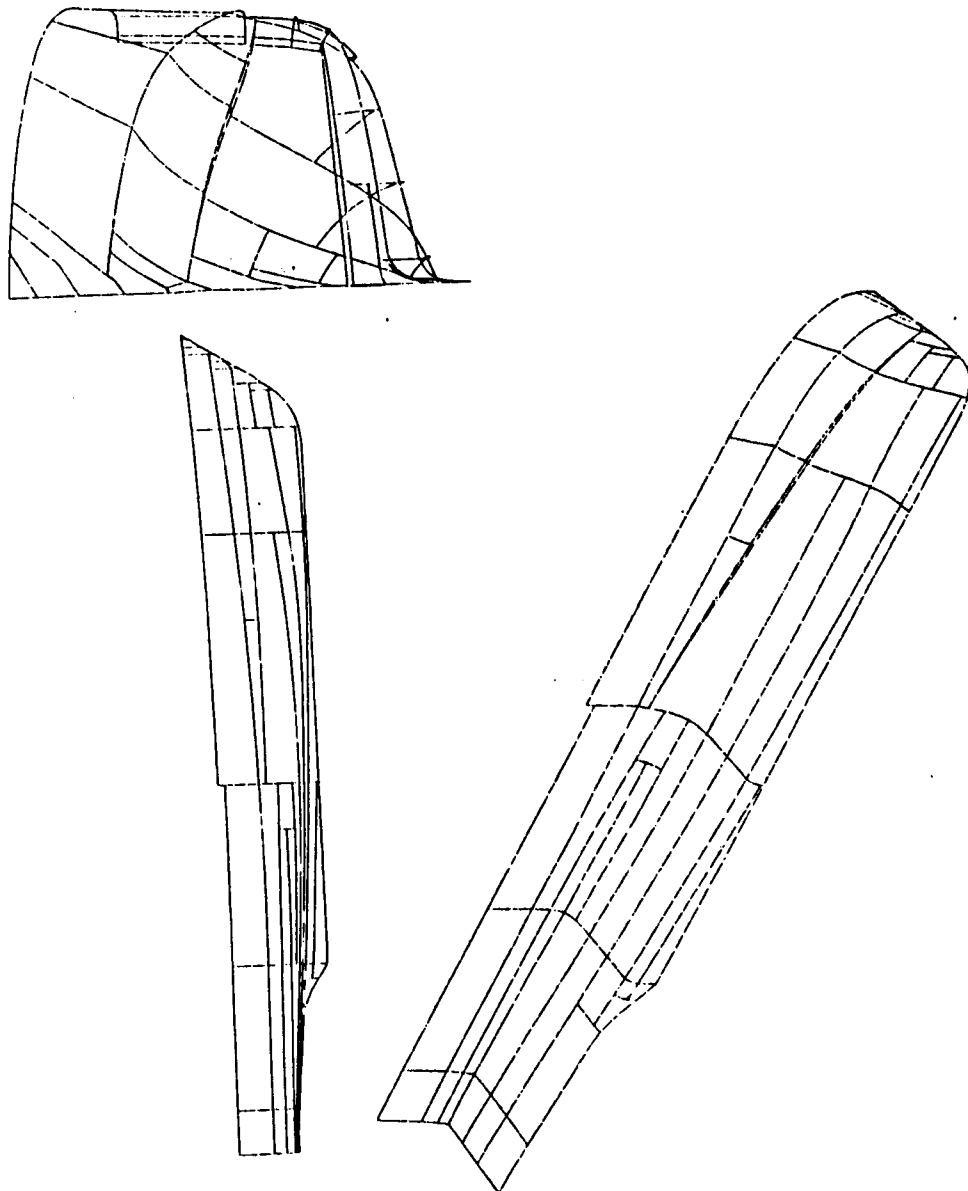These Lines Correspond to Frame Locations

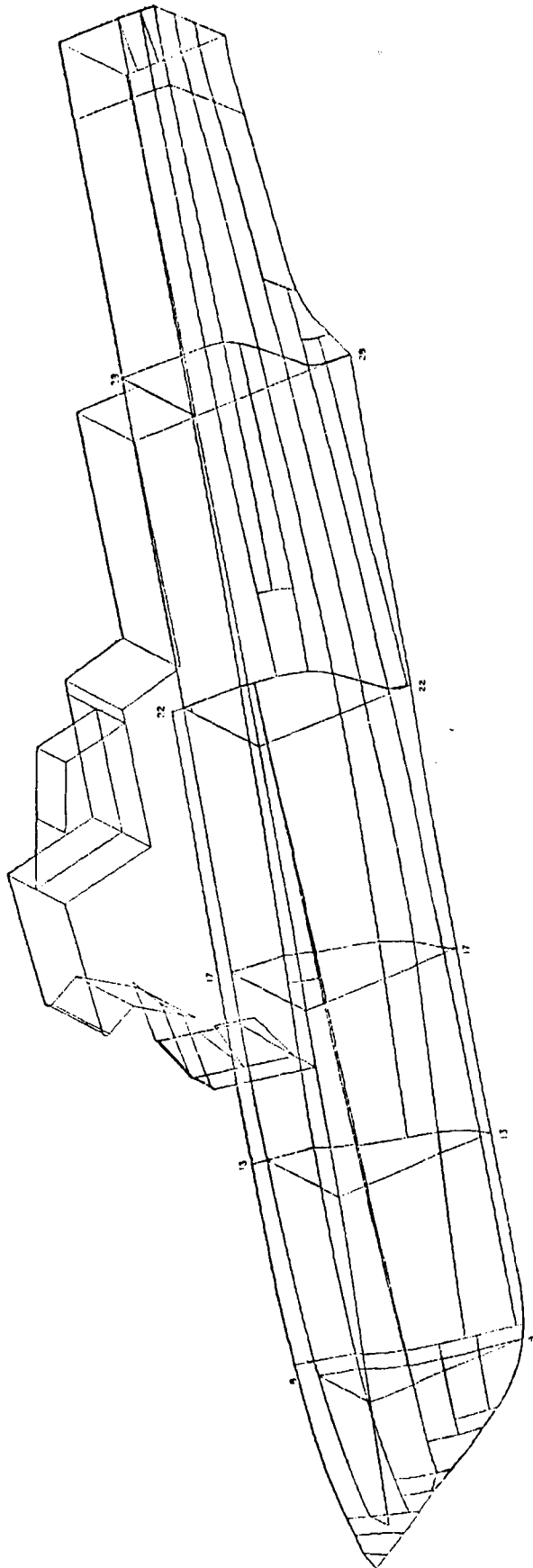Figure 3   B-Spline Fit of Lines Forming Surfaces That Define Hull Form

Figure 4

Final Configuration of Hull Surfaces and Superstructure Before Meshing.
Major Bulkheads at Frames 8, 13, 17, 22, and 28 are shown.

Figure 5

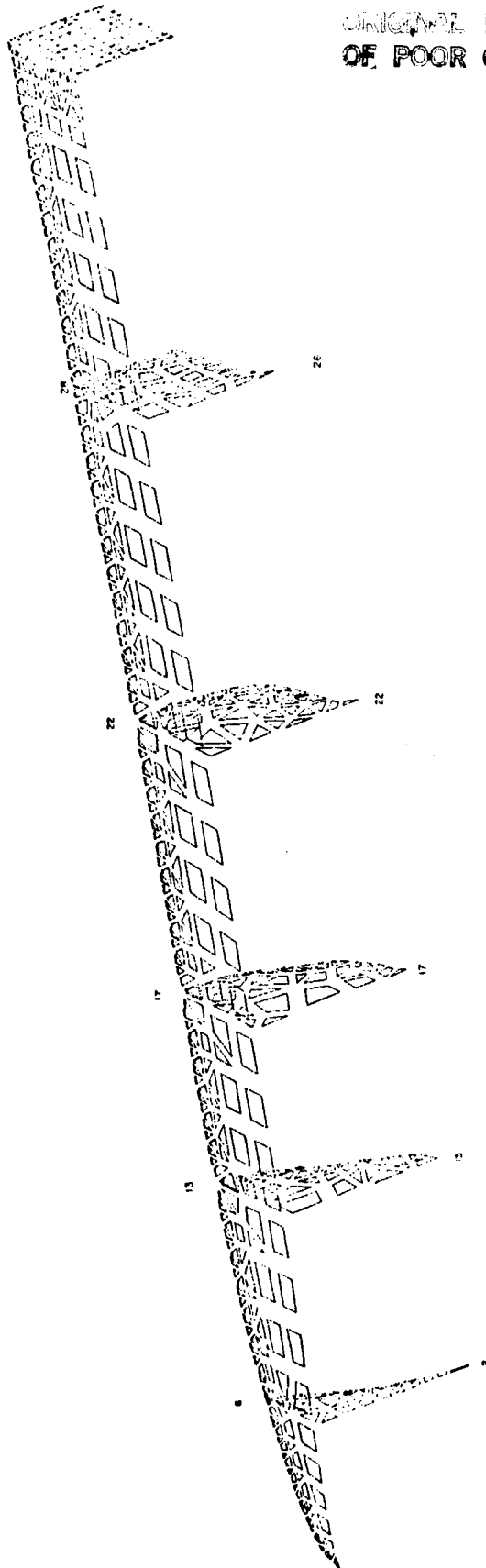Finite Element Model of Main Deck, Transom, and Five Major Bulkheads
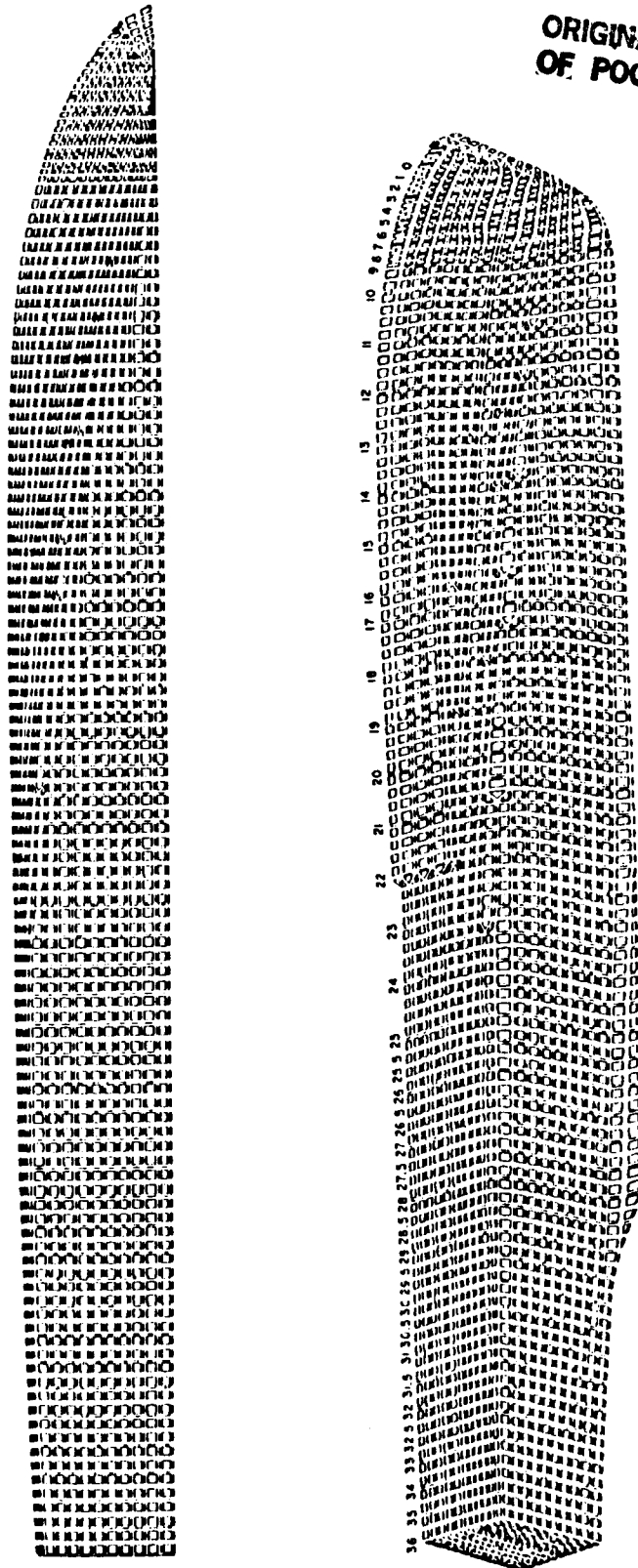
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Figure 6   Finite Element Model of All Hull Platings Including Transom
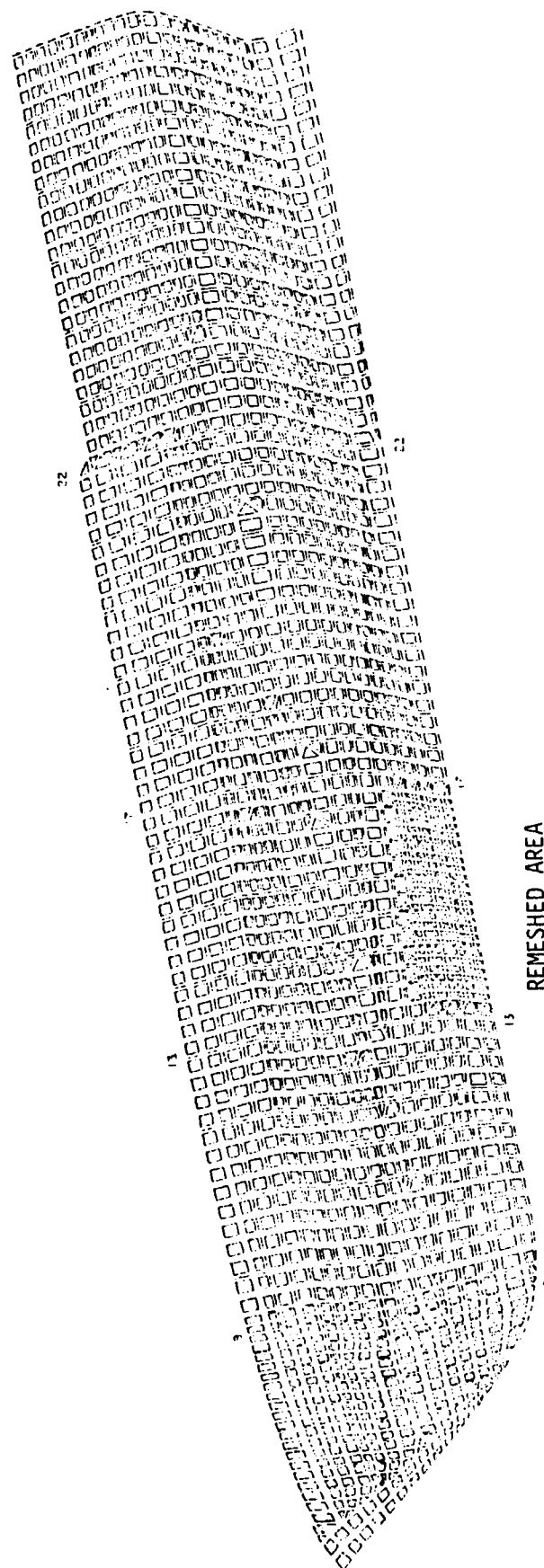
REMESHED AREA

Figure 6A

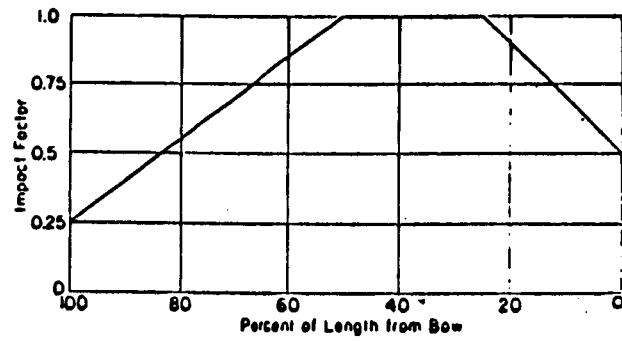Finite Element Model of Hull Plating with Remeshed Area Between Frames 13 and 17

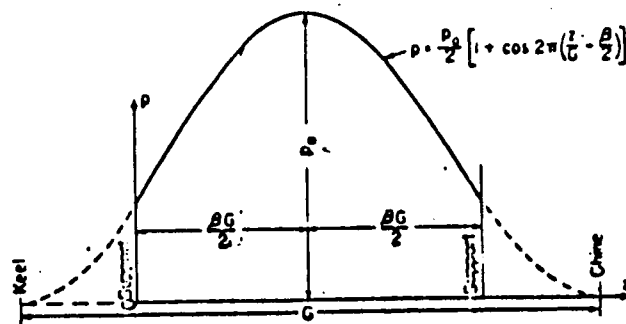296

FIG. 7.—IMPACT FACTOR AS A FUNCTION OF DISTANCE FROM BOW

$$p = \frac{p_o}{2}\left[1 + \cos 2\pi\left(\frac{z}{G} - \frac{\beta}{2}\right)\right]$$

FIG. 8.—GEOMETRY AND NOTATION OF TRANSVERSE LOAD
DISTRIBUTION

SUPERSTRUCTURE
LOADS

MACHINERY
LOADS

GRAVITY LOAD
OF HULL PLATE
AND STIFFENERS

TANKAGE
LOADS

BUOYANCY LOAD
ON EACH WETTED
NODE

PLANING LOAD
AS PER HELLER
JASPER

Figure 8A   Schematic Representation of Loads Applied to WPB Hull

$Po = 25PSI$ $Po = 15PSI$

$Po = 25PSI$	$Po = 15PSI$
48387.	29032.
45164.	27098.
41942.	25165.
38719.	23231.
35437.	21298.
32274.	19364.
29052.	17431.
25829.	15497.
22607.	13564.
19384.	11630.
16162.	9697.
12939.	7763.
9717.	5830.
6494.	3896.
3272.	1963.
49.2	29.4

$WP8 COAST GUARD 110 FT. F.E.M
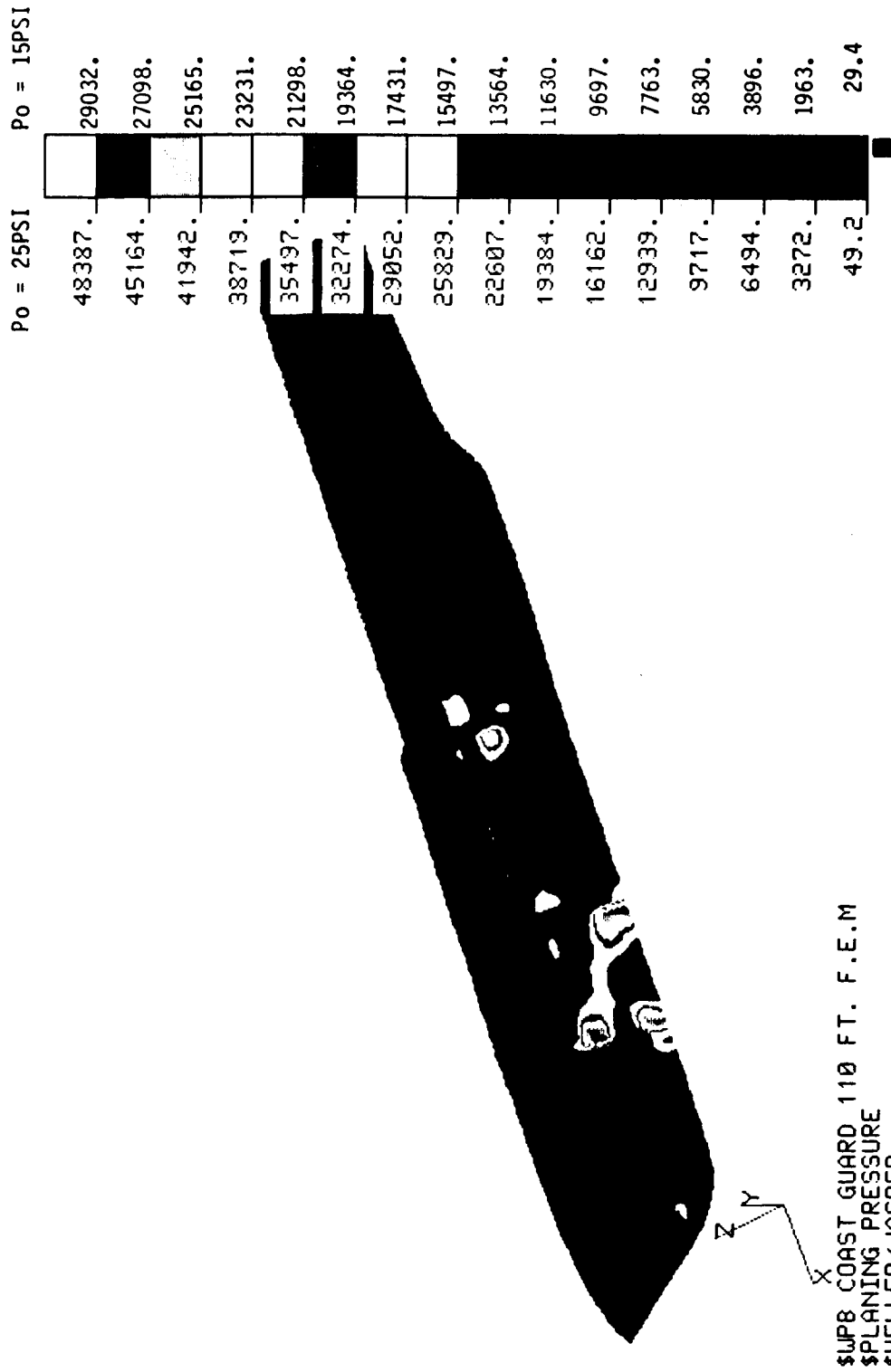$PLANING PRESSURE
$HELLER/JASPER

Figure 9

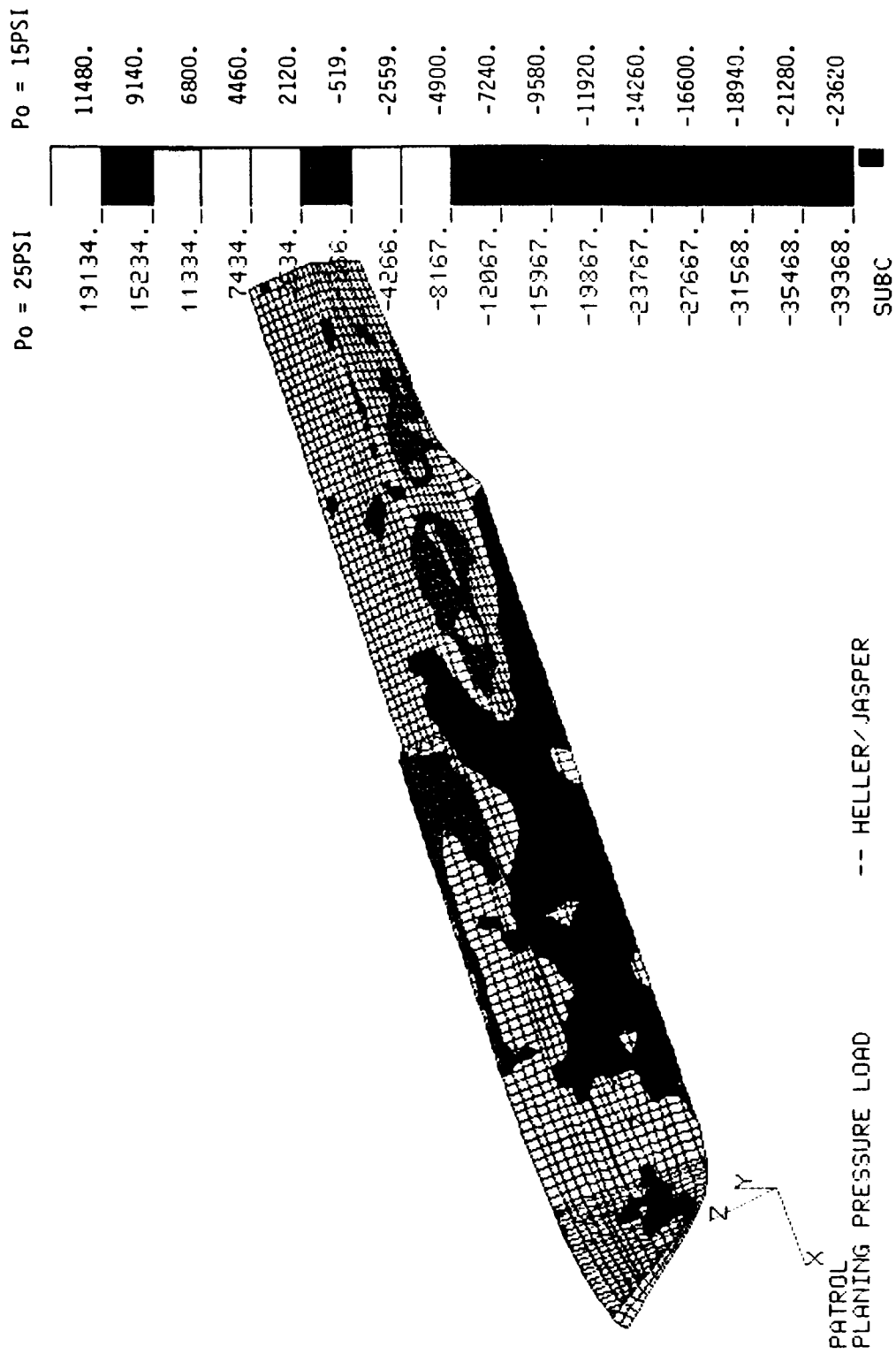Von Mises Stress Distribution on Entire Hull Plating
For Po = 25PSI and Po = 15PSI

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Figure 10 - Minimum Principal Stress on Entire Hull Plating For Po = 25 PSI and Po = 15 PSI
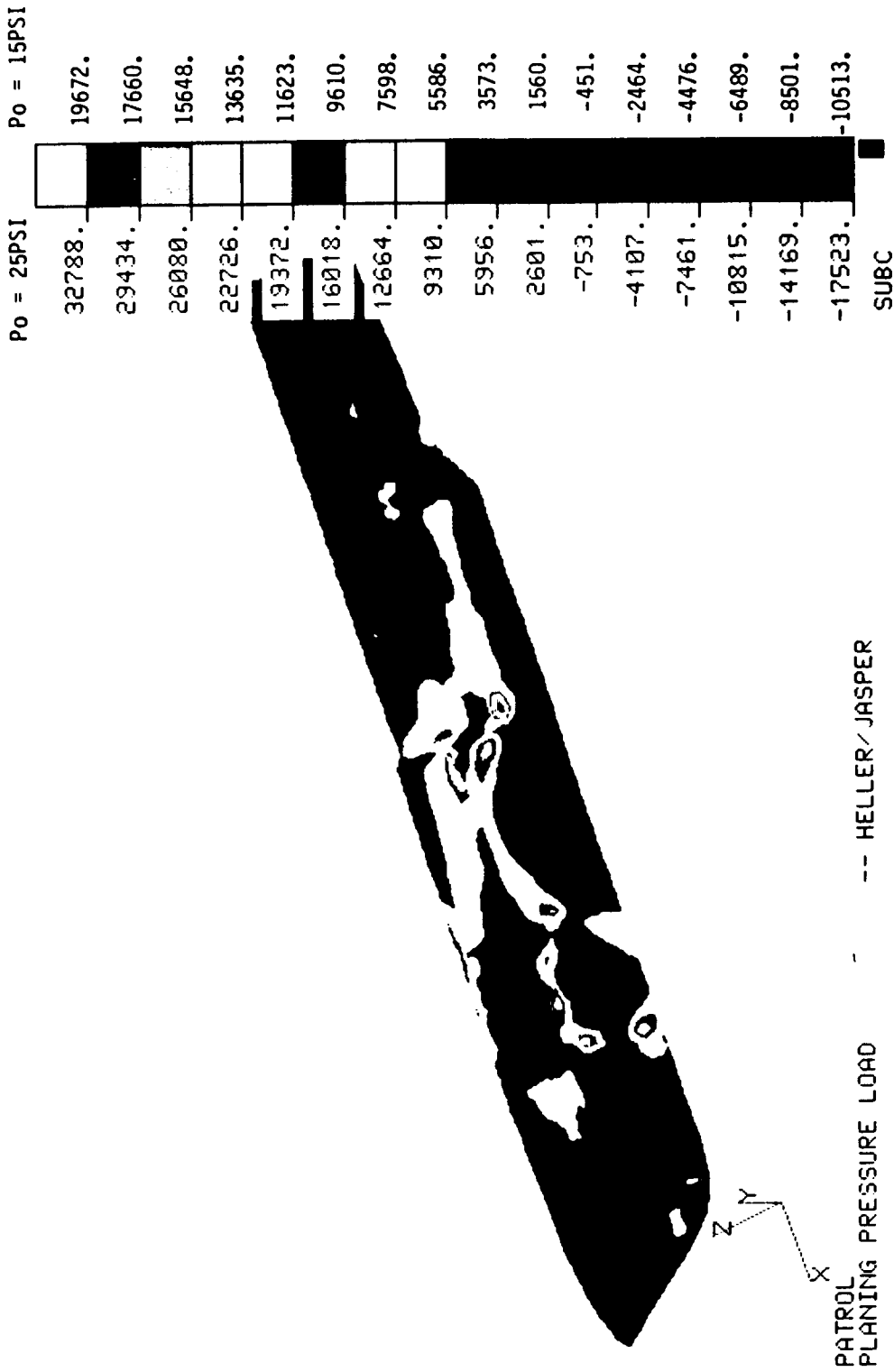
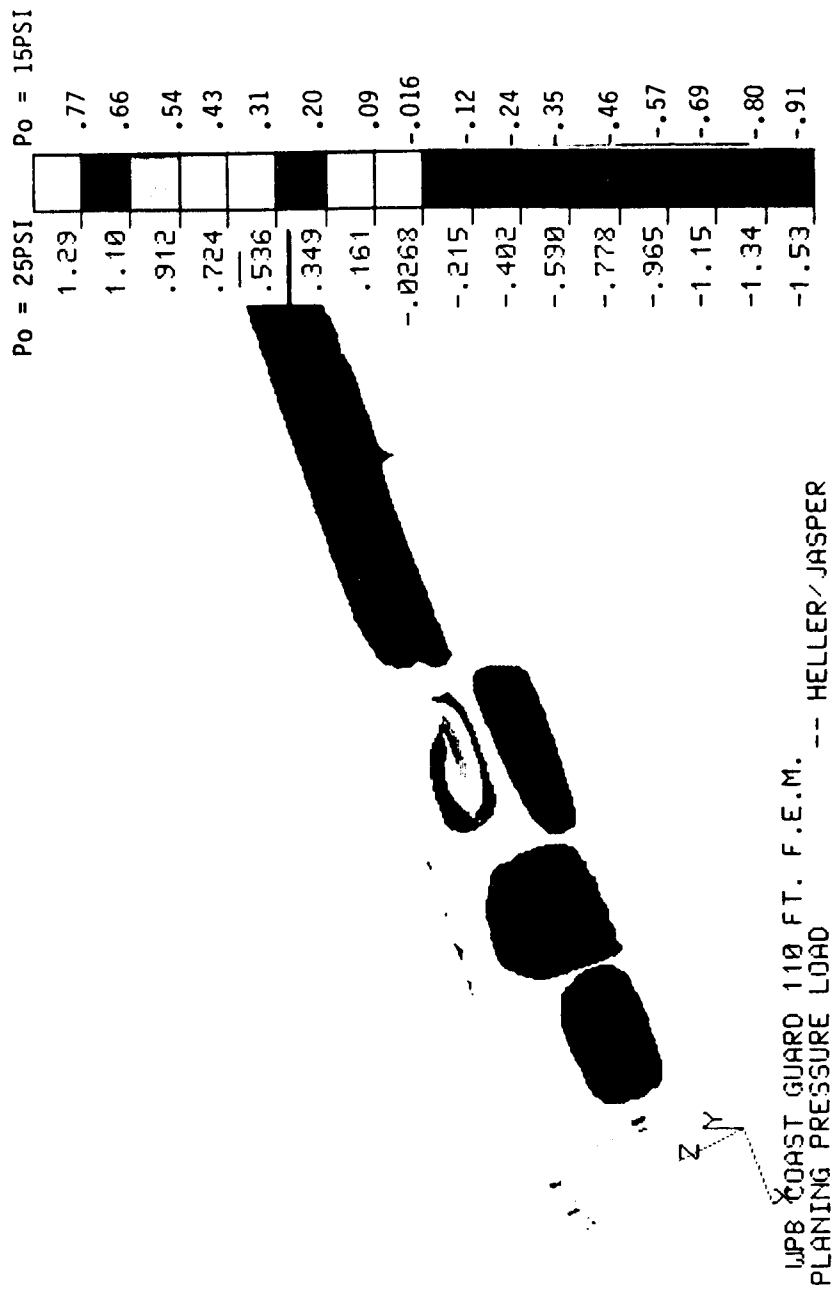Figure 11 – Maximum Principal Stress on Entire Hull For Po = 25 PSI and Po = 15 PSI

Figure 12 - Displacements in the Y Direction (INCHES) For Po = 25 PSI and Po = 15 PSI

Po = 25PSI	Po = 15PSI
1.59	.95
1.42	.85
1.24	.74
1.07	.64
.892	.53
.717	.43
.542	.32
.368	.22
.193	.11
.0179	.01
-.157	-.09
-.332	-.19
-.507	-.30
-.682	-.40
-.856	-.51
-1.03	-.61

WPB COAST GUARD 110 FT. F.E.M. -- HELLER/JASPER
PLANING PRESSURE LOAD
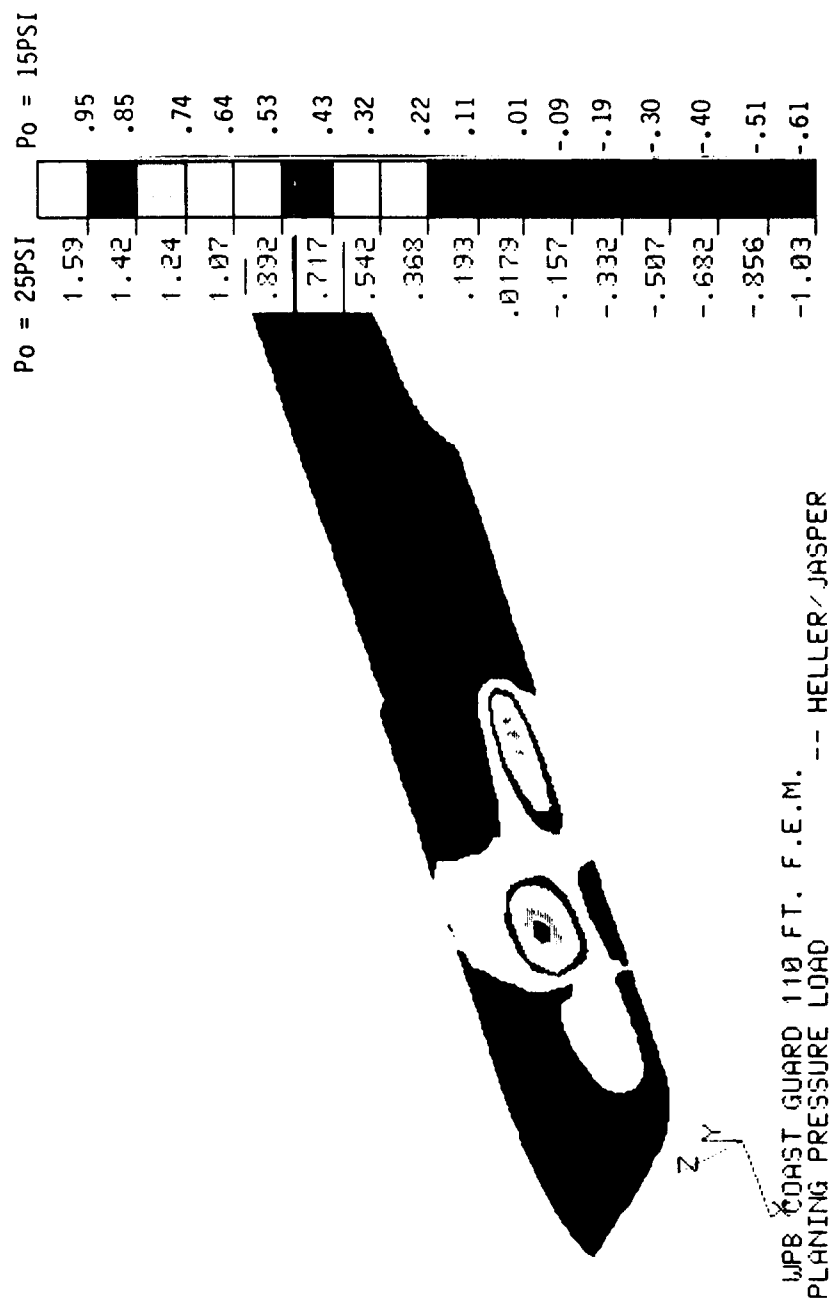
Figure 13 -- Displacements in the Z Direction (INCHES) For Po = 25 PSI and Po = 15 PSI

Po = 10PSI   Po = 15PSI

Po = 10PSI	Po = 15PSI
19540.	29310
18238.	27357
16937.	25405
15635.	23452
14334.	21501
13032.	19548
11731.	17596
10429.	15643
9128.	13692
7826.	11739
6525.	9787
5223.	7834
3922.	5883
2620.	3930
1319.	1978
17.5.	26.2
SUBC	

WPB COAST GUARD 110 FT. F.E.M. -- HELLER/JASPER
PLANING PRESSURE LOAD

Figure 14   Von Mises Stress Distribution on Entire Hull Plating
For Po = 15PSI and Po = 10PSI

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Figure 15
Displacements In the Y Direction (INCHES)
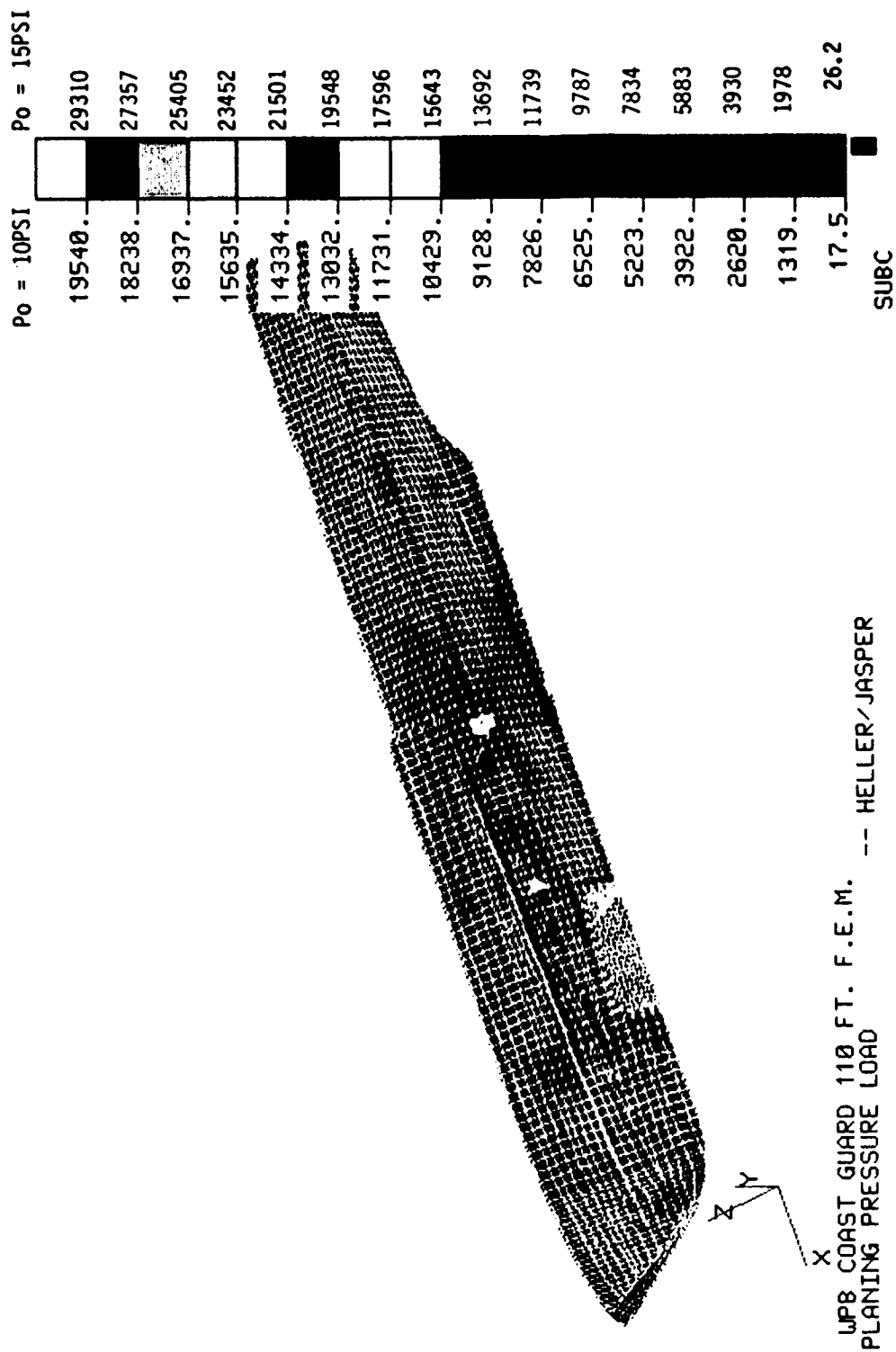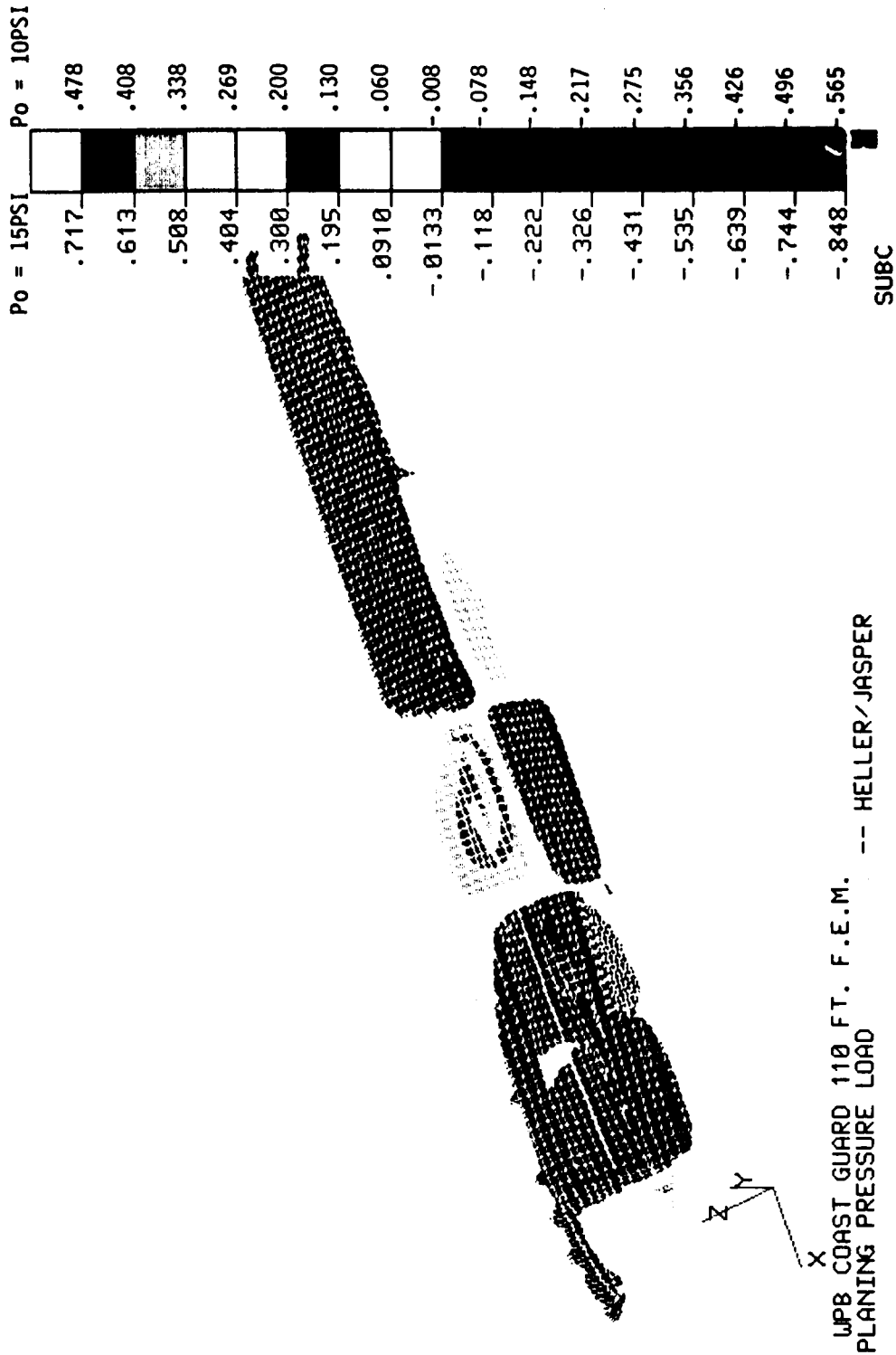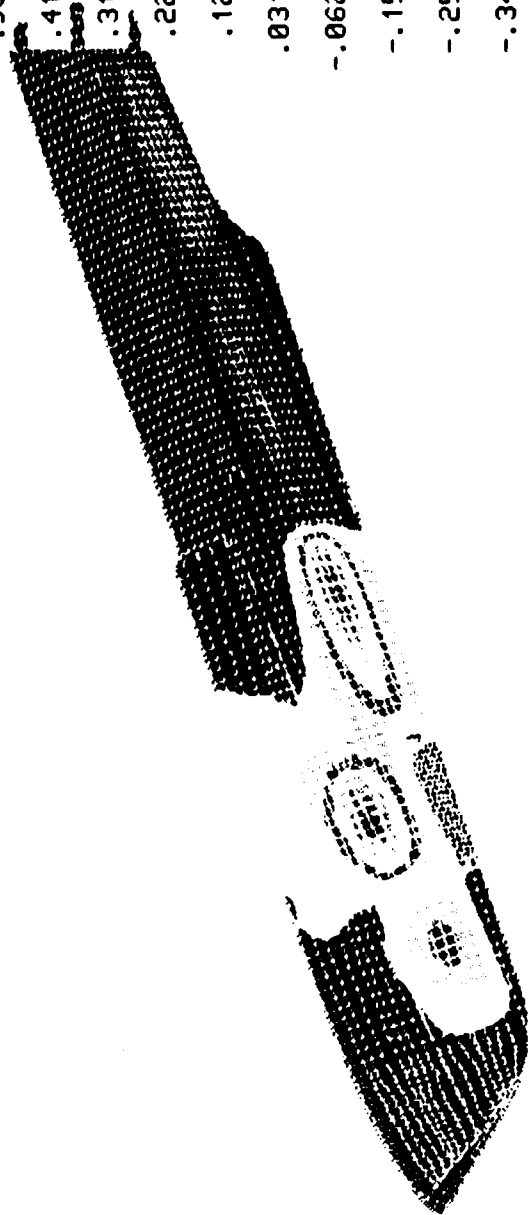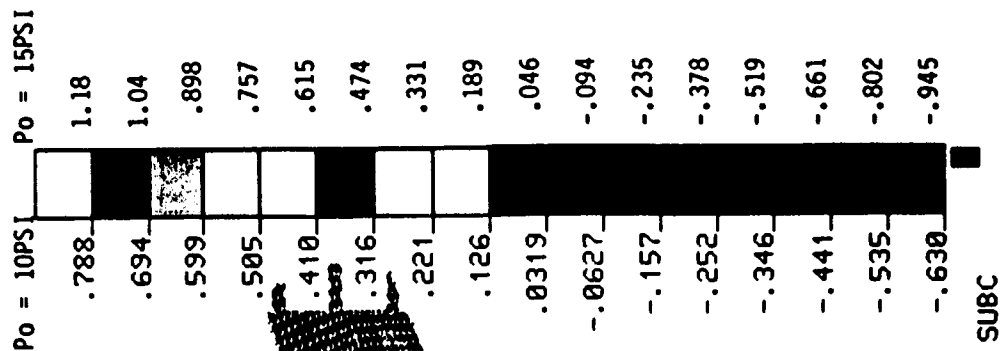For Po = 15PSI and Po = 10 PSI

WPB COAST GUARD 110 FT. F.E.M. -- HELLER/JASPER
PLANING PRESSURE LOAD

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Po = 15PSI

Po = 10PSI	Po = 15PSI
.788	1.18
.694	1.04
.599	.898
.505	.757
.410	.615
.316	.474
.221	.331
.126	.189
.0319	.046
-.0627	-.094
-.157	-.235
-.252	-.378
-.346	-.519
-.441	-.661
-.535	-.802
-.630	-.945

SUBC

WPB COAST GUARD 110 FT. F.E.M. -- HELLER/JASPER
PLANING PRESSURE LOAD

Figure 16
Displacements in the Z Direction (INCHES)
For Po = 15PSI and Po = 10PSI

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